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(71) Applicant: **FUJIKURA LTD.**
1-5-1 Kiba
Koto-ku Tokyo 135(JP)

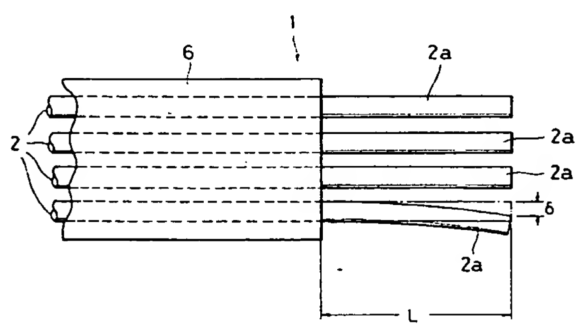
(72) Inventor: **Suzuki, Naomichi**
1-14-28 Shimoichiba
Uachiyo-chi, Chiba 276(JP)

(74) Representative: **Füchsle, Klaus, Dipl.-Ing. et al**
Hoffmann . Eitle & Partner Patentanwälte
Arabellastrasse 4
W-8000 München 81(DE)

(54) **Optical fiber cable.**

(57) The invention relates to an optical fiber cable of a multi-core single-mode type which consists of a series of groups of a plurality of optical fibers (2) having end portions (2a) fusion spliced to corresponding end portions (2a) of adjacent groups of optical fibers (2) at an optical connection loss of at most 0.5dB. Each of the end portions (2a) has a radius of curvature in meters defined by λ/1.41 (where λ is a wavelength in μ m at which said optical fiber cable is used). This structure ensures a sufficiently low optical connection loss of the optical fibers (2) which are economically connected in batch and are easily reconnected in case of trouble.

FIG.8



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This invention relates to an optical fiber cable and more particularly to an optical fiber cable of multi-core single-mode type formed by fusion splicing of the corresponding ends of optical fibers in batch.

As the demand for optical fiber cables in communication network systems has been increased, there have been developed optical fiber cables each of which comprises serially arranged optical fiber ribbons each having a plurality of optical fibers of multi-core single-mode type arranged in parallel to one after another. For efficient manufacturing purpose, the abutting ends of the optical fibers in adjacent optical fiber ribbons are fusion spliced.

Currently widely known optical fiber cables are of multi-mode type having a large diameter of 50 μ m or more and of single-mode type having a small core diameter such as 8 to 10 μ m.

End portions of optical fibers of single-core single-mode type are easily fusion spliced by aligning the opposed pair of end portions with each other under the observation on a display. It was confirmed that the single-core single-mode optical fibers achieve a low optical connection loss, more specifically an optical connection loss of 0.05dB or less.

On the other hand, optical fibers of multi-core type are fusion spliced on a fiber splicer in batch by causing the ends of the optical fibers of each optical fiber ribbon to abut against the corresponding ends of the optical fibers in the optical fiber ribbon adjacent to said each optical fiber ribbon without checking whether or not each pair of the end portions of the optical fibers are aligned with each other because of a large number of pairs of optical fibers to be fusion sliced.

As shown in Fig. 1, the end portions of optical fibers 101 exposed from a pair of ribbons are laid in V-grooves 110a formed in a pair of blocks 100 so as to be disposed opposed to each other. Thereafter, the optical fibers 101 on the two blocks 100 are moved toward each other to cause the ends of the optical fibers 101 on one block 100 to abut against the corresponding ends of the optical fibers 101 on the other block 100, and the end portions of the optical fibers 100 are fusion spliced in batch in a short time.

In this fusion splicing of the optical fibers 101 of multi-core type, the opposed ends of the optical fibers in both ribbons are not always accurately aligned because of bending of the end portion of each optical fiber. During the fusion splicing, the opposed end portions of optical fibers 101 on the blocks 100 are attracted toward each other by the surface tension exerted on the molten parts of the end portions of fibers such that they are aligned with each other.

More specifically, in ideal cases, the opposed ends of the corresponding two optical fibers 100 on both blocks 101 to be fusion spliced are normally displaced transversely from each other before fusion splicing, as shown in Fig. 2. As the end portions are molten by the fusion heat produced by arc discharge between electrodes, both the optical fibers 100 are attracted toward each other by the surface tension in an abutted state, as shown in Fig. 3. Finally, the ends of both optical fibers are self-aligned with each other and are connected together, as shown in Fig. 4.

In the optical fibers of multi-mode type having a diameter of 50 μ m or more, fusion splicing of the ends of the two optical fibers are approximately ideally performed because of their larger diameter, and in consequence the corresponding ends of the optical fibers in the adjacent optical fiber ribbons can be easily fusion spliced in batch at a low optical connection loss.

In the optical fibers of multi-core single-mode type having a diameter of 8 to 10 μ m, however, the fusion splicing cannot always be performed in an ideal way, although the ends of the both optical fibers themselves can be aligned with each other due to the surface tension. More specifically, when the ends of the two optical fibers 101 are transversely displaced much before splicing, as shown in Fig. 5, the cores 103 in the respective fibers 101 are deformed and are not aligned with each other after fusion splicing, as shown in Fig. 6, resulting in poor quality of optical fiber cables in respect of a large optical connection losses. When, for example, the displacement between the free ends of the cores of corresponding two optical fibers is 12 μ m, multi-core single-mode optical fibers used at a wavelength of 1.55 μ m exhibits such a large optical connection loss as 1dB.

The conventional method and the difficulty in splicing fine optical fibers are described in "Development of Arc Fusion Splicer for Ribbon Fiber MF-3S by Tsutomu Onodera et al., Fujikura Technical Review 1990, pages 37 to 42.

It was considered that such a large optical connection loss takes place, on one hand, due to the difference of the outer diameters between two optical fibers to be fusion spliced, including the difference occurring from dust attached to the peripheral surfaces of the optical fibers and, on the other hand, due to the misalignment of the V-grooves formed in both blocks. However, currently manufactured optical fibers have accurate outer diameters and dust on their peripheral surfaces is carefully removed when they are fusion spliced. Further, the V-grooves in both blocks can be accurately formed so as to be accurately aligned with each other. Accordingly, it was found that large optical connection loss does not occur from either

cause and the cause which produces such a large optical connection loss had not been known before the inventor of this invention found it.

It is accordingly the object of this invention to provide an optical fiber cable of multi-core single-mode type comprising a plurality of optical fibers having a small core diameter.

In order to attain the object, an optical fiber cable of multi-core single-mode type comprises a series of groups of a plurality of optical fibers having end portions fusion spliced to corresponding end portions of the adjacent groups of optical fibers at an optical connection loss of at most 0.5dB, each of said end portions having a radius of curvature in meters defined by:

at least $\lambda/1.41$

where λ is a wavelength, in μ m, at which the optical fiber cable is used.

For an optical fiber cable of multi-core single-mode type used at a wavelength of 1.3 μ m, the radius of curvature of the end portion of each optical fiber is at least 0.9 meter or more in order to attain an optical connection loss of at most 0.5dB.

Further, for an optical fiber cable of multi-core single-mode type used at a wavelength of 1.55 μ m has a radius of curvature of 1.1 meters or more to achieve an optical connection loss of at most 0.5dB.

Still further, the core diameter of each optical fiber may be 8 to 10 μ m.

The fusion splicing of optical fibers according to this invention allows for economically manufacturing optical fiber cables having an optical connection loss of 0.5dB or less by fusion splicing a plurality of thin optical fibers of multi-core single-mode type in a batch manner. In addition, optical fibers can be easily reconnected in case of trouble.

This invention will be described in detail by way of embodiments with reference to accompanying drawings in which:

Fig. 1 is a perspective view of a fusion splicer for optical fibers arranged in optical fiber ribbons;

Fig. 2 is a side view of the abutted end portions of two optical fibers held on a pair of V-groove blocks;

Fig. 3 is a side view of optical fibers whose end portions are being fusion spliced and are attracted toward each other by the surface tension;

Fig. 4 is a side view of end portions of the optical fibers which are fusion spliced in an ideal way;

Fig. 5 is a side view of end portions of two conventional optical fibers which are held on opposed V-groove blocks and which are bent so as to be much deviated transversely from each other;

Fig. 6 is a side view showing the misalignment of the free ends of the cores of the fusion spliced optical fibers of the prior art when the optical fibers are held on the V-groove blocks in a misaligned state as shown in Fig. 5;

Fig. 7 is a perspective view showing how to effect the fusion splicing of the end portions of optical fibers according to this invention;

Fig. 8 is a plan view of an end portion of one optical fiber in Fig. 7, in which the curvature of the end portion is exaggeratedly shown in order to explain the principle of this invention;

Fig. 9 is a plan view of end portions of optical fibers arranged in an optical fiber ribbon according to this invention, in which the curvature of the end portion of one optical fiber is also exaggeratedly shown;

Fig. 10 is a graph showing relationships between the curvatures and the optical connection losses of optical fibers used at a wavelength of 1.3 μ m according to this invention; and

Fig. 11 is a graph showing relationships between the curvatures and the optical connection losses of optical fibers used at a wavelength of 1.55 μ m according to this invention.

The inventor of this invention found that the misalignment of the facing ends of the cores of the optical fibers each having a core diameter of 8 to 10 μ m mainly occurs from random bending of the end portion of optical fibers which bending is adversely and inherently generated when the optical fibers are manufactured and he confirmed that this random bending chiefly causes an optical connection loss over 1dB.

As shown in Fig. 7, a pair of groups of optical fibers of multi-core single-mode type having a diameter of 8 to 10 μ m in two optical fiber ribbons (each ribbon containing four optical fibers 2, i.e., a four-core ribbon in this embodiment) are held in the parallel V-grooves 6a formed in blocks 6 such that the exposed end portions 2a of the optical fibers 2 extend from the bases 6 by a length L. When the curvature of the end portion 2a of an optical fiber 2 is constant, the amount of deviation δ is proportional to the extended length L of the exposed end portion 2a of the optical fiber 2. The shorter the extended length L, the smaller the amount of deviation δ. In this respect, it is preferred that the extended length L of the end portion 2a of each optical fiber 2 be made as short as possible. However, the distance G between the V-groove blocks 6 must be at least 5 to 6 mm in order to heat the end portions 2a of the optical fibers 2 stably and fully by arc discharge produced between electrodes 7 and 7A.

The principle of this invention will now be explained with reference to Figs. 8 and 9.

Suppose that R is the radius of curvature of the extended end portion 2a of an optical fiber 2. Then,

$$R^2 = L^2 + (R - \delta)^2$$

where R, L and δ are expressed in meters and L is approximately equal to G/2.

Therefore,

$$R = (L^2 + \delta^2)/2\delta \quad (1)$$

The inventor of this invention made experiments to find the relationships between the curvatures (which are reciprocals of the radii of curvature and their unit is expressed in 1/meter) and the optical connection losses of fusion spliced multi-core single-mode optical fibers used at a wavelength of 1.3 μ m and at a wavelength of 1.55 μ m.

First series A and AA of the experiments for both wavelengths were made by bending the opposed end portions 2a of the paired optical fibers 2 at the same curvature in the opposite directions such that the largest difference existed between the extreme ends of the paired optical fibers 2.

Second series B and BB of the experiments for both wavelengths were carried out by bending the end portion 2a of one of the paired optical fibers 2 and by rendering straight the opposed end portion 2a of the other optical fiber 2 such that the cores 4 in the clads 5 of the paired optical fibers 2 (Fig. 7) were deviated transversely by half a distance of the distance between the cores of the first series A and AA.

The results of the experiments are shown in Fig. 10 for the wavelength of 1.3 μ m and in Fig. 11 for the wavelength of 1.55 μ m.

When the curvature is 2/meter or the radius of curvature R is 0.5 meter, the optical connection losses at the 1.3 μ m wavelength are substantially 1.6dB for the optical fibers of the first series A and substantially 0.4dB for the optical fibers of the second series B, and the optical connection losses at the 1.55 μ m wavelength are substantially 2.4dB for the optical fibers of the first series AA and substantially 0.6dB for the optical fibers of the second series BB. It is understood that the optical connection loss of the optical fibers at the 1.55 μ m wavelength is larger than that at the 1.3 μ m wavelength, since the core diameter of the optical fibers at the 1.55 μ m wavelength is smaller than that at the 1.3 μ m wavelength.

The experiments lead to the following relationships between the amounts of traversal core displacements δ and the optical connection losses:

$$\alpha = \alpha_0 \cdot \delta \quad (2)$$

where α is the optical connection loss and α_0 is a constant uniquely determined from the mode field diameter of an optical fiber; and

$$\alpha \doteq 5 \times 10^{-3}\ \mathrm{dB}/\mu\ \mathrm{m}^2$$

for an optical fiber at the 1.3 μ wavelength; and

$$\alpha \doteq 7.2 \times 10^{-3}\ \mathrm{dB}/\mu\ \mathrm{m}^2$$

at an optical fiber for the 1.55 μ wavelength.

Since the transmission loss of optical fibers of 0.2 to 0.3dB/Km or less can be obtained in optical fiber network systems and the average optical connection loss of substantially 0.05dB is attained for single-core optical fibers, it is preferred in optical fibers at wavelengths of 1.3 and 1.55 μ m that the average optical connection loss be substantially 0.1dB and the maximum connection loss allowance be substantially 0.5dB in order to obtain economical and practical communication network system.

As shown in Figs. 10 and 11, the points X and Y which are the intersections of the ordinates indicating the optical connection loss of 0.5dB and the curves of the series A and AA of the experiments fall on the values of 1.1 and 0.92/meter on the abscissas indicating curvatures, respectively. In other words, the radii of curvature at the wavelength of 1.3 μ m and the wavelength of 1.55 μ m are 0.92 meter (approximately 0.9 meter) and 1.1 meters, respectively.

Since 1.3 / 0.92 = 1.41 and 1.55/1.1 = 1.41, it should be rationalized that the radii of curvature R of optical fibers which have the optical connection loss of 0.5dB are expressed by:

$$R = \lambda / 1.41 \text{ in meters} \quad (3)$$

where λ is a wavelength in μ m at which the optical fibers are used.

Optical fibers which satisfy the condition expressed by Equation (3) are obtained by manufacturing them accurately under the fully controlled manufacturing conditions or by selecting suitable optical fibers.

Embodiments of optical fiber cables according to this invention are constituted by fusion splicing the above-mentioned embodiments of the optical fibers in batch.

In place of optical fibers of ribbon type, there may be used any batched form of optical fibers such as a plurality of optical fibers so arranged in a loose tube or the like that their opposed ends can be spliced together in batch.

Reference signs in the claims are intended for better understanding and shall not limit the scope.

Claims

1. An optical fiber cable of multi-core single-mode type comprising a series of groups of a plurality of optical fibers (2) having end portions (2a) fusion spliced to corresponding end (2a) portions of adjacent groups of optical fibers (2),
   characterized in that
   each optical fiber (2) has an optical connection loss of at most 0.5dB, each of said end portion (2a) having a radius of curvature in meters defined by:

   at least $\lambda/1.41$

   where λ is a wavelength, in μ m, at which said optical fiber cable is used.

2. The optical fiber cable according to claim 1, characterized in that said optical fiber cable (2) is used at a wavelength of 1.3 μ m and said radius of curvature is at least 0.9 meters.

3. The optical fiber cable according to claim 1, characterized in that said optical fiber cable (2) is used at a wavelength of 1.55 μ m and said radius of curvature is at least 1.1 meters.

4. The optical fiber cable according claim 2 or claim 3, characterized in that each of said optical fibers (2) has a core diameter of 8 to 10 μ m.

FIG.1

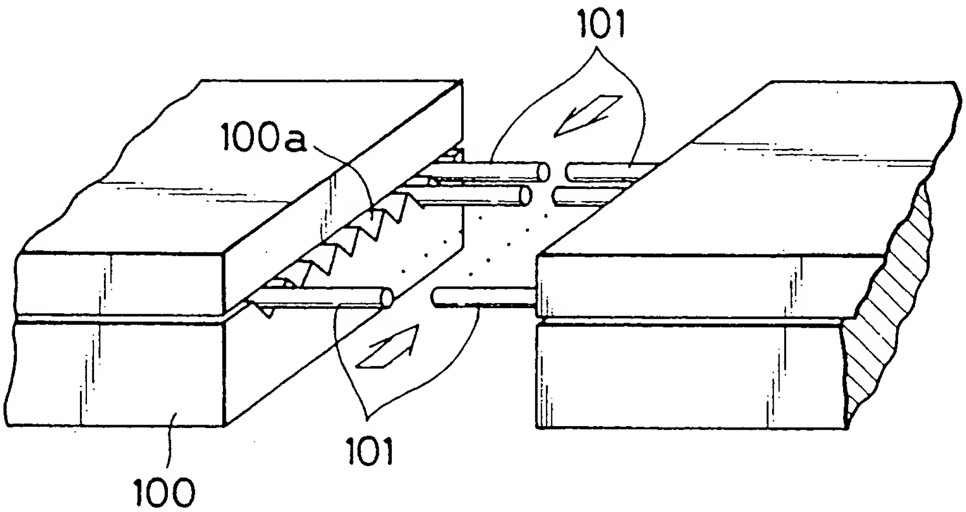


FIG.7

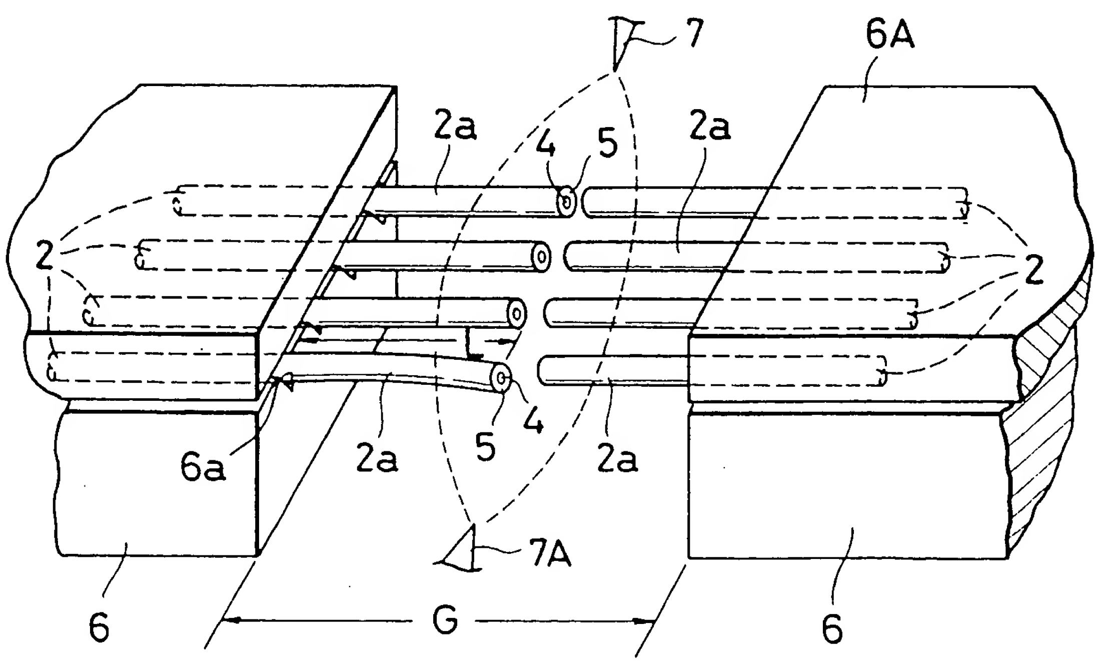


FIG.2

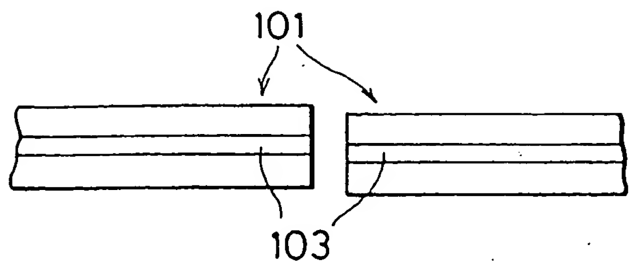


FIG.3

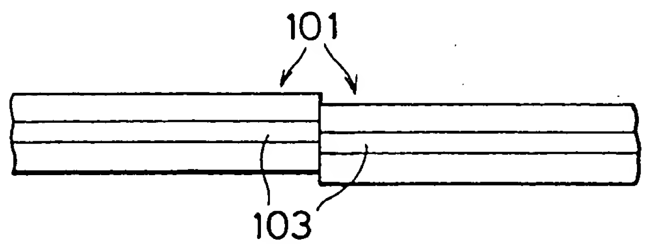


FIG.4

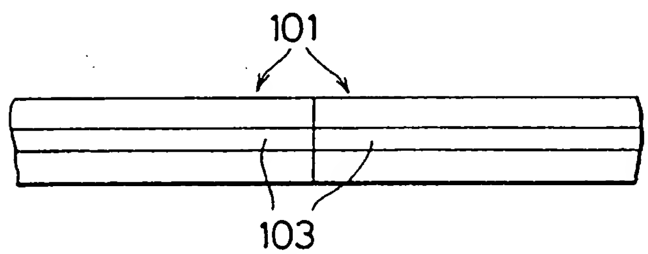


FIG.5

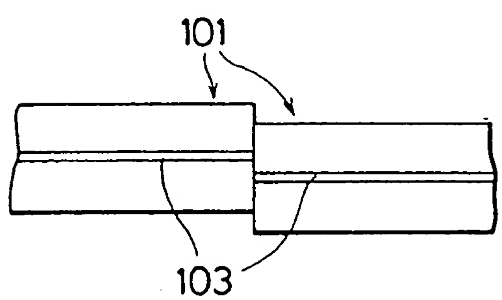


FIG.6

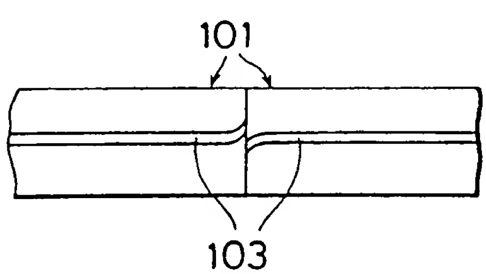


FIG.8

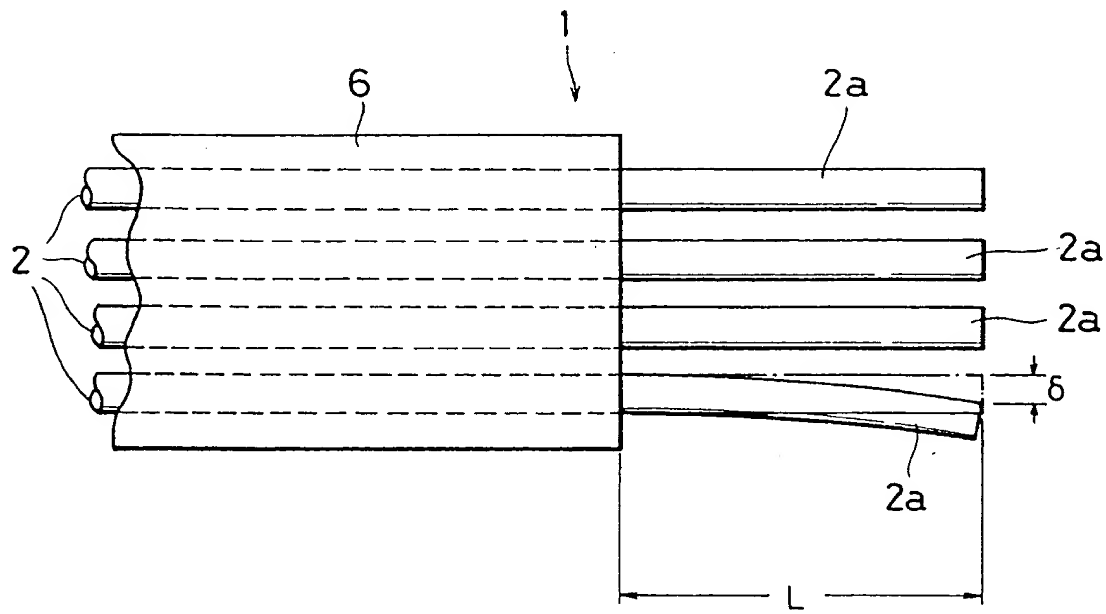


FIG.9

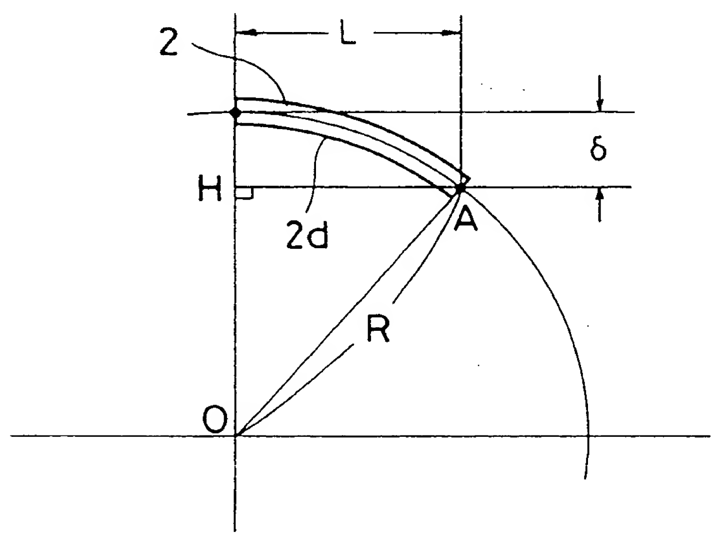


FIG.10

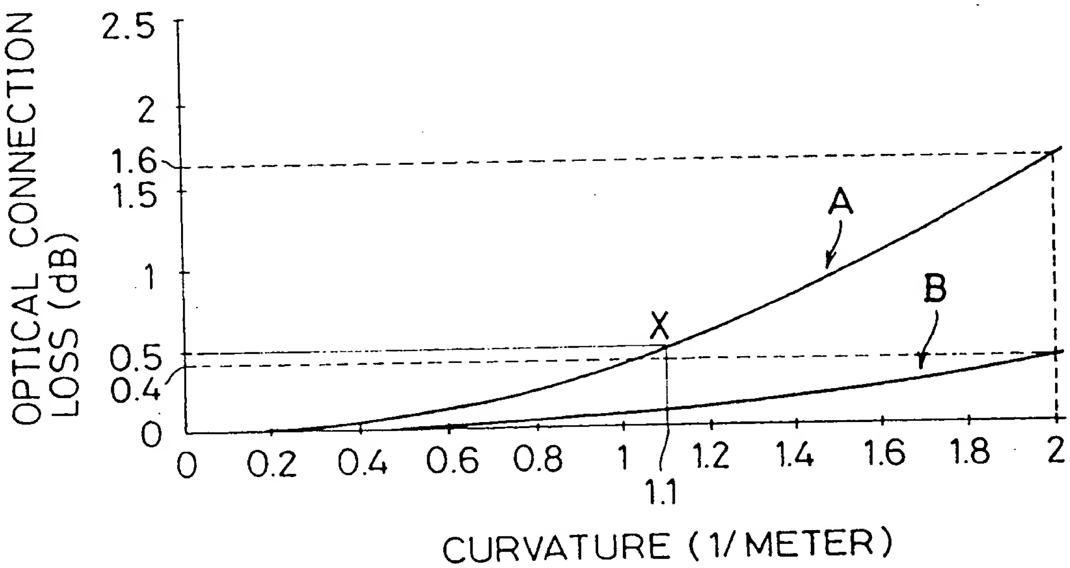
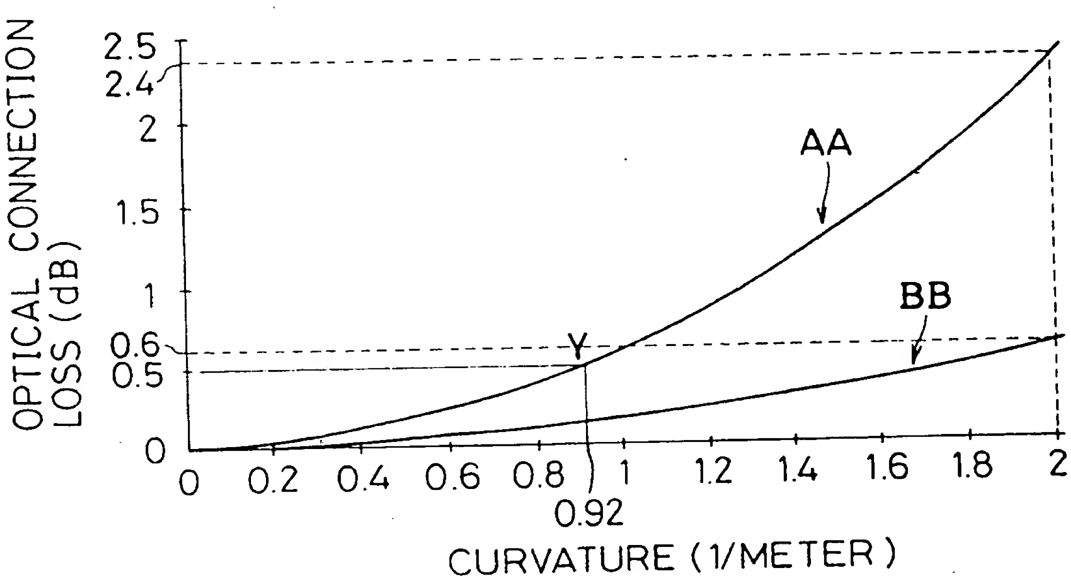

OPTICAL CONNECTION LOSS (dB)
2.5
2
1.6
1.5
1
0.5
0.4
0
A
B
X
0
0.2
0.4
0.6
0.8
1
1.1
1.2
1.4
1.6
1.8
2
CURVATURE (1/METER)

FIG.11


OPTICAL CONNECTION LOSS (dB)
2.5
2.4
2
1.5
1
0.6
0.5
0
AA
BB
Y
0
0.2
0.4
0.6
0.8
0.92
1
1.2
1.4
1.6
1.8
2
CURVATURE (1/METER)

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91121633.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 5)
A	EP - A - 0 382 511 (NIPPON ELECTRIC) * Column 1, lines 26-41; column 6, lines 39-51; claim 1 * --	1,4	G 02 B 6/40 G 02 B 6/255
A	US - A - 4 893 892 (ZIEMEK et al.) * Column 3, line 13 - column 5, line 23 * --	1	
A	APPLIED OPTICS, vol. 23, no. 3, February 1984, M. TACHIKURA "Fusion mass--splicing for optical fibers using electric discharges between two pairs of electrodes" pages 492-498 * Chapters I,III,IV * ----	1	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

G 02 B 6/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	06-03-1992	GRONAU

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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